EMITTANCE MEASUREMENT WIZARD AT PITZ

A.Shapovalov[1] and L.Staykov[2], DESY, Zeuthen, Germany

Abstract

The Photo Injector Test Facility at DESY, Zeuthen site (PITZ) develops electron sources of high brightness beams, required for linac based free electron lasers (FELs) like FLASH or the European XFEL. One of the key issues in electron beam optimization is the minimization of the transverse emittance. The main method to measure emittance at PITZ is a single slit scan technique, implying local beam divergence measurement by insertion of the slit mask at a definite location within the beam and measurements of the transmitted beamlet profile downstream of the slit station. "Emittance Measurement Wizard" (EMWiz) is the program used by PITZ operators for automated emittance measurements. EMWiz combines an acquisition program for beam and beamlet image recording and a postprocessing tool for the analysis of the measured transverse phase space of the electron beam. It provides a way to execute the difficult emittance measurements in an automatic mode and to get a calculated emittance result.

INTRODUCTION

At the PITZ facility, the electron source optimization process is conducted. The goal is to reach the XFEL specifications of 0.9 mm mrad at a bunch charge of 1 nC. The research activities at PITZ include the production, optimization and characterization of electron sources with a small normalized projected transverse emittance. The transverse emittance is a key property of high brightness electron sources and the key value for the measurements at PITZ [1]. This task of emittance measuring is organized at PITZ through the emittance measurement wizard (EMWiz) software. This advanced high-level software application interacts through a Qt [2] graphical user interface with the DOOCS [3] and TINE [4] systems for machine control and ROOT [5] for data analysis and visualization. For communication with the video system and acquiring images from cameras at several screen stations, a set of video kernel libraries have been created [6]. In this paper, details about the Emittance Measurement System for both hardware and software parts are described.

_____

shapovalov.mephi@yandex.ru
[1] On leave from NiYaU MEPhI, Moscow Russia

lazaraza@ifh.de
[2] On leave from INRNE, Sofia, Bulgaria

EMITTANCE MEASUREMENT HARDWARE

The transverse emittance and phase space distribution are measured at PITZ using the single slit scan technique [7, 8]. The Emittance Measurement SYstem (EMSY) consists of horizontal and vertical actuators with 10 and 50 μm slits masks and YAG/OTR screens for the beam size measurement. The slit mask angle can be precisely adjusted for the optimum angular acceptance of the system (Figure 1). Three EMSY stations are located in the current setup as shown in Figure 2. The first EMSY station (EMSY1) behind the exit of the booster cavity is used in the standard emittance measurement procedure. It is at 5.74 m downstream of the photocathode corresponding to the expected minimum emittance location. For this technique, the local divergence is estimated by transversely cutting the electron beam into thin slices. Then, the size of the beamlets created by the slits is measured at the YAG screen at some distance downstream the EMSY station. The 10 μm slit and a distance between the slit mask and the beamlet observation screen of 2.64 m are used in the standard emittance measurement. Stepper motors are applied to move each one of the four axes separately. They give the precise spatial positioning and orientation of the components. On each of the actuators, either a YAG or OTR screen is mounted to observe the beam distribution. A single and a multi slit masks are mounted consecutive to take samples from the transverse phase space of the electron beam. A CCD camera is used to observe the images on the screens (see Figure 1).
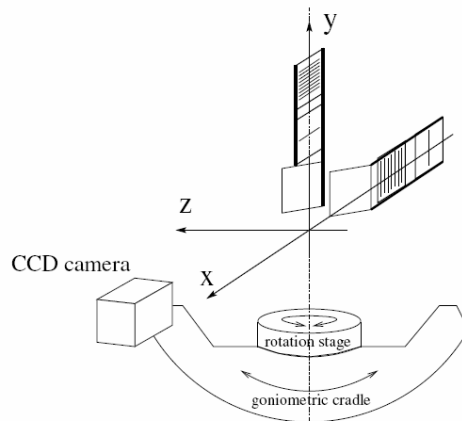

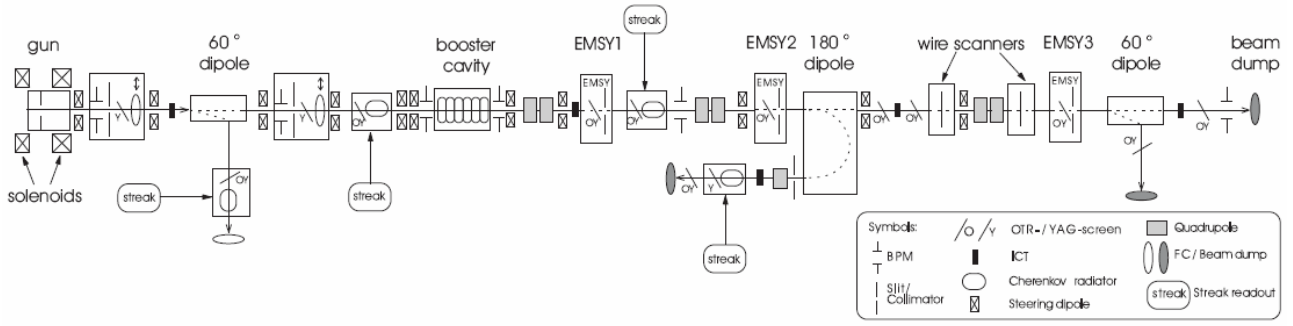Figure 1: Layout of the Emittance Measurement System.

Figure 2: Layout of the Photo Injector Test facility at DESY, Zeuthen site (PITZ).

EMITTANCE MEASUREMENT ANALYSIS

A schematic representation of the single slit technique is shown in Figure 3. For this technique the local divergence is estimated by transversely cutting the electron beam into thin slices and measuring their size on a screen after propagation in a drift space. The so called 2D-scaled emittance is then calculated using the following definition [1]:

$$\varepsilon_n = \beta\gamma \frac{\sigma_x}{\sqrt{\langle x^2 \rangle}} \sqrt{\langle x^2 \rangle \cdot \langle x'^2 \rangle - \langle xx' \rangle^2} \qquad (1)$$

Here $\langle x^2 \rangle$ and $\langle x'^2 \rangle$ are the second central moments of the electron beam distribution in the trace phase space obtained from the slit scan, where $x' = p_x / p_z$ represents the angle of a single electron trajectory with respect to the whole beam trajectory. The RMS beam size is measured on an additional YAG screen at the position of the slit. The local divergence is obtained by analyzing the profiles of the beamlets produced from the slit at some distance downstream. There, the spatial distribution of the beamlets corresponds to the local divergence $\langle x'^2 \rangle_{local}$, which can be derived from the size of the beamlet using:

$$\sqrt{\langle x'^2 \rangle_{local}} = \frac{\sqrt{\langle x^2_b \rangle}}{L_d} \qquad (2)$$

Here $\sqrt{\langle x^2_b \rangle}$ is the RMS size of the beamlet on the screen after the distance L_d. The total uncorrelated divergence of the beam is estimated by a weighted average of several measurements of the local divergence $\langle x'^2 \rangle_i$ taken from different locations across the beam:

$$\langle x'^2 \rangle = \sum_{i=1}^{N} \omega_i \cdot \langle x'^2 \rangle_i \qquad (3)$$

Here weights ω_i are based on a ratio of pixel sum of the ith beamlet to the pixel sum of all beamlets. The Lorentz factor $\beta\gamma$ is measured using a dispersive section downstream of EMSY.
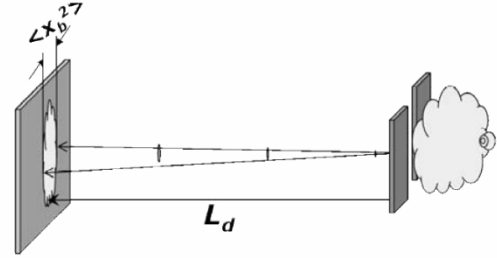

Figure 3: Schematic representation of the single slit scan technique.

The factor $\sigma_x / \sqrt{\langle x^2 \rangle}$ is applied to correct for possible sensitivity limitation of low intensity beamlets, where σ_x is the rms whole beam size measured at the slit location. In the emittance measurement setup and procedure, intrinsic cuts have been minimized by e.g. using highly sensitive screens, a 12 bit signal resolution CCD-camera and a large area of interest to cover the whole beam distribution. Therefore, emittance value is called 100% rms emittance. The measurement system was optimized to measure emittance as low as 1 mm mrad for 1 nC charge per bunch with precision about 10 %.

EMITTANCE MEASUREMENT WIZARD

This wizard is a multithread, multiprocessor, multiwindow application with user-friendly interface, flexible design which based on XML-config-file. It is created for 64 bits Scientific Linux CERN version 5.0.

Before using the wizard for measurement, the machine parameters have to be adjusted. Some necessary values, e.g. gun and booster energy, laser beam rms size are measured by other tools and put in the corresponding proper field of EMWiz. In principle the wizard is a set of tools and automatic procedures for emittance measurements, to collect experimental data and to analyze the data.

The video system at PITZ has 24 digital cameras with 8 and 12 effective bits per pixel and 7 video servers [6]. The video part (Figure 4) of EMWiz manages the cameras by reading properties, changing settings and connecting to a video server. The client makes it possible to get the video image, to apply filters, to grab and to save video images.
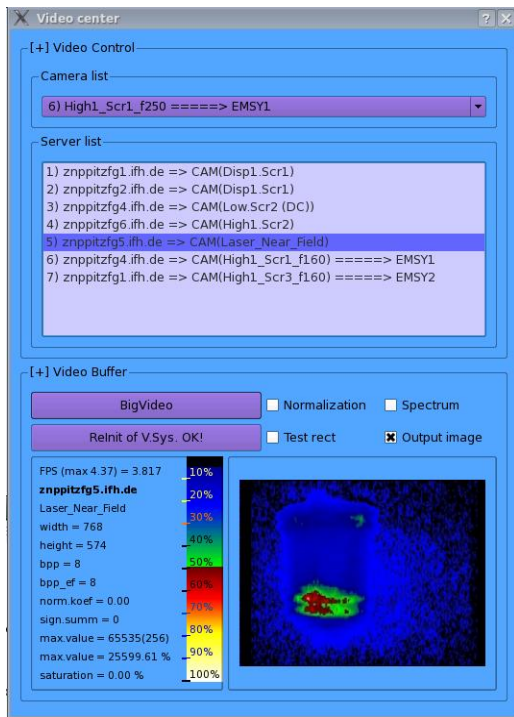

Figure 4: Video component of EMWiz.

Calculation of important values is going simultaneously with the drawing process. Control of saturation is one important criteria for obtaining good data quality. The calculated saturation parameter gives
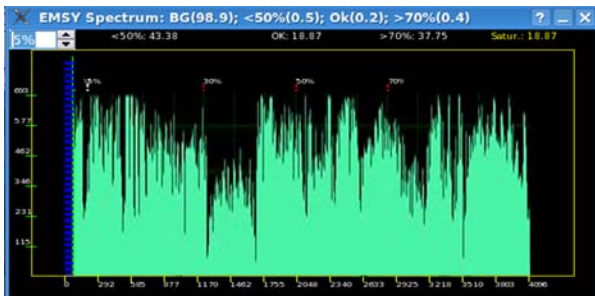

Figure 5: Spectrum tool.

more reliable results than visual observation on the video image.

Currently, the following instruments are available: spectrum, find best angle and prescan. The spectrum tool shows the number of pixels in the image with a given intensity (Figure 5). Major part of image pixels should have intensity between 50% and 70% of maximum intensity.

The tool "Find best angle" helps to find an optimum angle between the slit opening and the YAG screen in automatic mode. The total intensity signal depends on the angle between the slit opening and the beam axis. The maximum intensity is the desirable angular orientation.

The most complex tool is "PreScan". It is a hands-off procedure for signal quality testing and finding the scan limits of emittance measurements. In the past an operator did all measurements manually and the human factor could strongly affect on the result. The PreScan tool moves the EMSY slit between some selected limits and collects sets of image frames from a chosen camera.
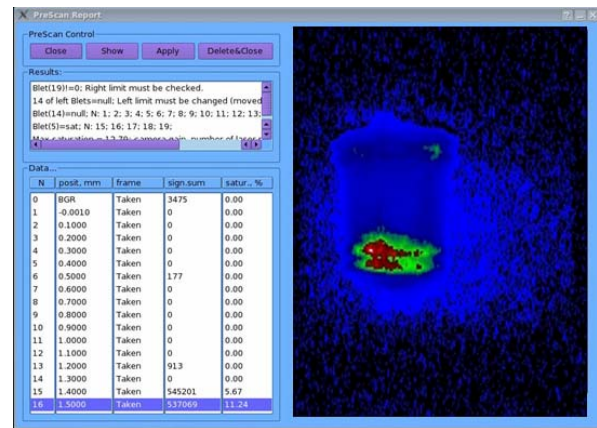

Figure 6: PreScan tool of EMWiz.

The next step is background frame collecting via controlling of the laser shutter. The wizard changes some parameters of the machine system and scan limits. In the final analysis, the tool generates a report with recommended settings for the EMWiz e.g. scan range, and the machine parameters (Figure 6). An operator has a choice to apply these settings or to make own corrections in difficult cases.

EMITTANCE MEASUREMENT PROCEDURE USING EMWIZ

At beginning, an operator chooses an EMSY station (EMSY1, EMSY2, EMSY3) and an axis (x or y axis) in the scan "Info center" panel (Figure 7). The step is the beamsize measurement at the slit and the beamlet observation screen locations using the YAG/OTR screen. The transverse beam images and background

frames at the slit location (EMSY) and at the beamlet screen (MOI) are recorded using the "Grab&Save" tool (Figure 8). These images are required for the emittance
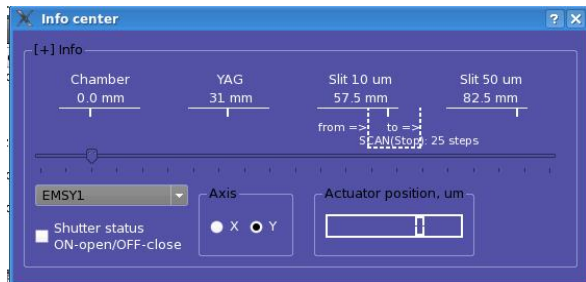

Figure 7: Scan info panel.

Figure 8: Scan & Grab control.

calculation using formula (1). Then, then beamlet scan procedure can be started. Presently, the algorithms are available:

a) The slit is moved through the beam within the scan limit and selected step (Figure 8). Video images and background frames are grabbed at each scan step. An operator changes the solenoid current and repeats the scan, including the procedure "PreScan". The measurement time for one given solenoid setting is about 30 minutes.

b) A new method "Fast Scan" improved the measurement time. This method was also implemented to EMWiz. Firstly, background statistics is collected. Next step, the slit is moved continuously with slow constant speed from the left to the right within the scan limit. At the same time, the selected CCD camera saves the image frames from the beamlet observation screen with fixed rate. The operator repeats the scan for all main solenoid current

values of interest. The measurement time for one solenoid setting is about 20 seconds.

The process of data collection in EMWiz stores all machine parameters continuously and informs the operator about critical fluctuations of controlled parameters (Figure 9), which can influence the measurement reliability. The data is recorded with cross-reference to the number of the grabbed frame. That means the actuator position, RF-power and gun temperature are known for each video frame. This gives possibility to process and explore data with more precision. The list of the parameters can be changed via an XML-config file. This GUI is based on a config file and can be easily transformed with new demands.
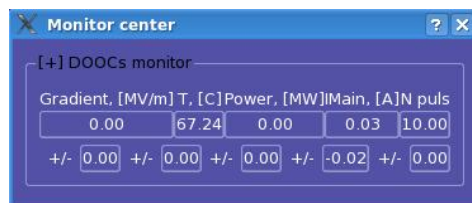

Figure 9: System monitoring.

The EMWiz has a black box feature. All actions of the operator to the program and machine, system status, error events and alarms with time-stamp are stored to a log-file. With help of an expert, one can open a hidden window (Figure 10), to support the shift crew remotely for fixing of a problem.

The last step in the measurement is to calculate the emittance using the "calculator" tool. The operator sets a folder with saved data, and then the tool checks the data in this folder and shows only good data sets. A lot of data processing is ongoing during calculation. Different filters, formulas etc. can be applied to the data.

A user can select plotting options for to plot all intermediate results after each complex process. At the end of the calculation the emittance plot is shown by default (Figure 11). For the plotting ROOT was integrated to EMWiz.

Currently, the wizard consists of separated programs for each logical task. Communication between program components is realized by a shared memory. This approach gives the possibility to use EMWiz components on different user stations with starting on one host. This increases graphics productivity and decreases the CPU loading. In the future it is planned to add network communication to give possibility for using parts of the wizard on different machines.

The PITZ facility is updated continuously and development of EMWiz is also ongoing. The work with EMWiz is going in the directions of complete automation of the measurement process, improving the quality of the experimental data and calculation

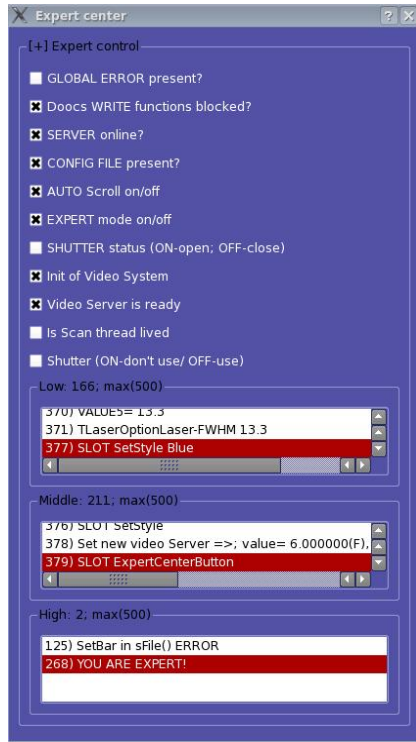algorithms for taking into account changing machine parameters during the measurement.
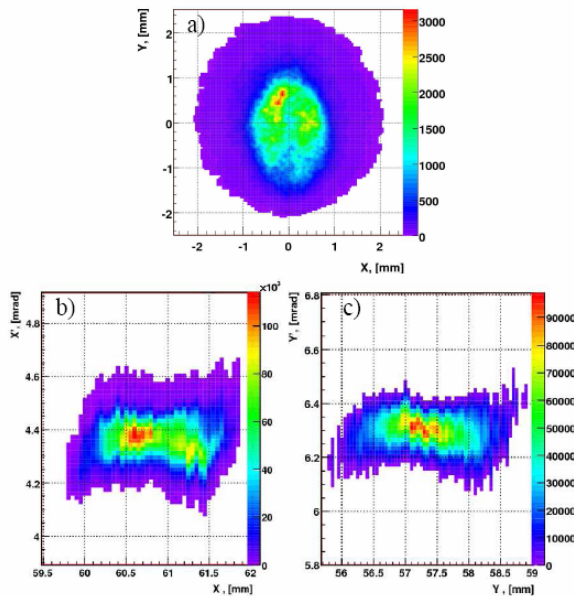

Figure 10: Expert window.

Figure 11: Transverse distribution (a), horizontal (b), and vertical (c) phase space for a give machine setup. The measured maximum mean longitudinal momentum of the beam for this point was 6.61 MeV/c after the gun acceleration and 14.6 MeV/c after the booster acceleration [1].

CONCLUSIONS

The Emittance Measurement Wizard (EMWiz), a semiautomatic emittance measurement client application. It strongly interfaces with the machine control and video system. EMWiz is one of the main measurement tools at PITZ. With the help of this program, the final emittance value can be measured much faster, more reliable, less attention requirement and user-interaction by operators. This is a big step forward in comparison to the emittance measurement solutions which have been used before. The majority of wizard components are universal and can be used for others tasks, not only for emittance measurement. Further development of this wizard will give new features for automatic data collection and analysis, which will result in decreasing of measurement time and increasing of measurement quality.

REFERENCES

[1] S. Rimjaem et al., "Recent emittance measurement results for the upgraded PITZ facility", Proceedings of FEL09, Liverpool, UK.

[2] http://qt.nokia.com

[3] http://tesla.desy.de/doocs/doocs.html

[4] http://adweb.desy.de/mcs/tine/

[5] http://root.cern.ch/drupal/

[6] Stefan Weisse et al., "TINE video system: proceedings on redesign". Proceedings of ICALEPCS 2009, Kobe, Japan.

[7] L. Staykov et al., Proceeding of the 29th International FEL Conference, Novosibirsk, Russia, 2007, MOPPH055, p. 138.

[8] F. Stephan, C.H. Boulware, M. Krasilnikov, J. Bahr et al.,"Detailed characterization of electron sources at PITZ yielding first demonstration of European X-ray Free-Electron Laser beam quality", Phy. Rev. St Accel. Beams 13, 020704 (2010)